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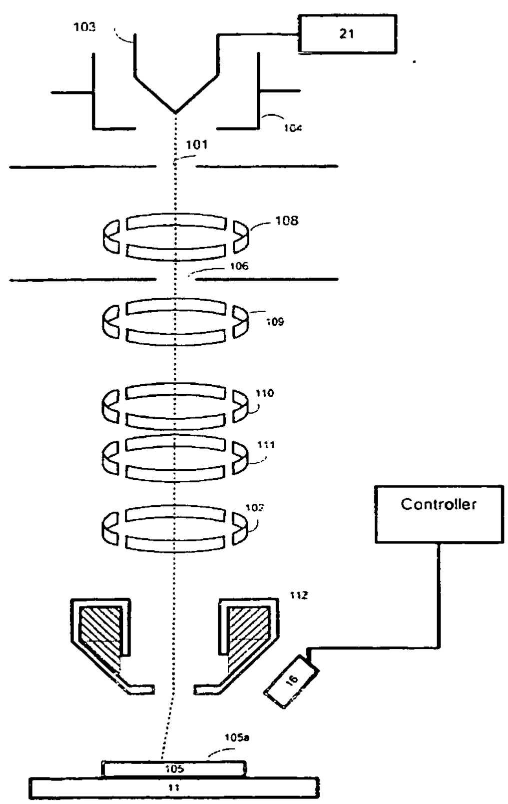

(57) Abstract: A method and system for determining a cross sectional feature of a structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a first and a second traverse sections. The method includes: (a) determining a first traverse section cross sectional feature in response to one or more scans of the structural element with an electron beam that is tilted at one or more corresponding tilt angle, such as to illuminate at least the top section and a first transverse section; (b) selecting, in response to a first parameter, whether to (i) determine a second traverse section cross sectional feature in response to the first traverse cross sectional feature, or (ii) to determine the second traverse section cross sectional feature in response to one or more scans of the structural element with an electron beam that is tilted at one or more corresponding tilt angle, such as to illuminate at least the top section and the second transverse section; and (c) determining the second traverse section cross sectional feature in response to the selection.

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A SYSTEM AND METHOD FOR DETERMINING A CROSS SECTIONAL FEATURE OF A STRUCTURAL ELEMENT HAVING A SUB-MICRON CROSS SECTION

RELATED APPLICATIONS

[001] This application claims the priority of U.S provisional application serial number 60/394864, filed 11 July 2002, titled "Using tilted SEM views for CD measurements".

FIELD OF THE INVENTIUON

[002] This invention relates to systems and methods for inspecting objects such as but not limited to semiconductors wafers, reticles, during fabrication and, in particular, for inspecting structural elements such as lines, contacts, trenches and the like.

BACKGROUND OF THE INVENTION

[003] Integrated circuits are very complex devices that include multiple layers. Each layer may include conductive material, isolating material while other layers may include semi-conductive materials. These various materials are arranged in patterns, usually in accordance with the expected functionality of the integrated circuit. The patterns also reflect the manufacturing process of the integrated circuits.

[004] Integrated circuits are manufactured by complex multi-staged manufacturing processes. During this multi-staged process resistive material is (i) deposited on a substrate/ layer, (ii) exposed by a photolithographic process, and (iii) developed to produce a pattern that defines some areas to be later etched.

[005] Various inspection and failure analysis techniques evolved for inspecting integrated circuits both during the fabrication stages, between consecutive manufacturing

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stages, either in combination with the manufacturing process (also termed "in line" inspection techniques) or not (also termed "off line" inspection techniques). Various optical as well as charged particle beam inspection tools and review tools are known in the art, such as the VeraSEM™, Compluss™ and SEMVision™ of Applied Materials Inc. of Santa Clara, California.

[006] Manufacturing failures may affect the electrical characteristics of the integrated circuits. Some of these failures result from unwanted deviations from the required dimensions of the patterns. A "critical dimension" is usually the width of a patterned line, the distance between two patterned lines, the width of a contact and the like.

[007] One of the goals of the inspection process is to determine whether the inspected objects includes deviations from these critical dimensions. This inspection is usually done by charged particles beam imaging that provide the high resolution required to measure said deviations.

[008] A typical inspected structural element is a line that has two opposing sidewalls. The measurement of the bottom width of the line involves measuring the top width of the line as well as measuring its sidewalls.

[009] Measurement of a structural element line critical dimensions using only a top view (in which the electron beam that scans the line is perpendicular to the substrate) may result in faulty results, especially when one of the sidewalls has a negative sidewall angle such that an upper end of the sidewall obscures a lower end of that sidewall.

[0010] In order to address said inaccuracies CD-SEM tools that enable electronic tilt of an electron beam were introduced. NanoSem 3D of Applied Materials from Santa Clara, is a fully automated CD-SEM that has a column that allows electronic

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tilting as well as mechanical tilting of the scanning electron beam to scan the wafer surface with various tilt angles from several directions.

[0011] Critical dimension measurement may involve illuminating an test object by multiple tilted beams and processing the detected waveforms to define critical dimensions.

[0012] Multiple measurements have some disadvantages. First, they reduce the throughput of the inspection system, especially when the measurement involves changing the tilt of scanning electron beam. Such a change may require a de-Gauess stage, as well as an electron beam stabilization stage. A further disadvantage of multiple measurements results from degradation (for example shrinkage and carbonization) of the measured structural element, as well as unwanted charging of the measured structural element.

SUMMARY OF THE INVENTION

[0013] The invention provides various scanning schemes that enable to selectively reduce the amount of measurements required for determining cross sectional features of structural elements.

[0014] The invention provides a method for determining a cross sectional feature of a structural element having a sub-micron cross-section (at least one of the cross section dimensions are below one micron), the cross section is defined by an intermediate section that is located between a first and a second traverse sections. The method includes: (a) determining a first traverse section cross sectional feature in response to one or more scans of the structural element with an electron beam that is tilted at one or more corresponding tilt angle, such as to illuminate at least the top section and a first transverse section; (b) selecting, in response to a first parameter, whether to (i) determine a second traverse section cross sectional feature in response

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to the first traverse cross sectional feature, or (ii) to determine the second traverse section cross sectional feature in response to one or more scans of the structural element with an electron beam that is tilted at one or more corresponding tilt angle, such as to illuminate at least the top section and the second transverse section; and (c) determining the second traverse section cross sectional feature in response to the selection.

[0015] According to an embodiment of the invention at one of the tilted angles can be substantially zero and even zero.

[0016] According to another aspect of the invention the tilt angle can be achieved by electrical tilt and/or mechanically tilt or a combination of both. Mechanical tilt can be achieved by tilting the inspected object and/or the electron beam column (or a portion of said column) or a combination of both.

[0017] The invention provides a method for determining a cross sectional feature of a structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a first and a second traverse section. The method includes: (a) scanning the structural element with an electron beam that is tilted at first positive angle in relation to an imaginary line perpendicular to the structural element, to provide a first set of data; (b) scanning the structural element with an electron beam that is tilted at second positive angle in relation to an imaginary line perpendicular to the structural element, to provide a second set of data, if the height of the structural element in not known or not estimated;(c)determining a first traverse section cross sectional feature in response of at least the first set of data; (d) determining a second traverse section cross sectional feature in response to the first traverse cross

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sectional feature, if a first parameter has a certain value; (e)whereas if the first parameter has another value performing the steps of: (e.1) scanning the structural element with an electron beam that is tilted at first negative angle in relation to an imaginary line perpendicular to the structural element, to provide a third set of data; (e.2) scanning the structural element with an electron beam that is tilted at second negative angle in relation to an imaginary line perpendicular to the structural element, to provide a fourth set of data, if the height of the structural element in not known or not estimated; whereas the height may extracted from the measurements of the first traverse section cross sectional feature, thus step (e.2) is usually not executed; (e.3) determining a second traverse section cross sectional feature in response of at least the third set of data.

[0018] The invention provides an system for determining a cross sectional feature of a structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a first and a second traverse sections, the system includes: (a) first means for generating an electron beam;(b) second means for scanning the electron beam across a structural element of a measured object and for determining a tilt angle of the electron beam; whereas the second means is connected to and controlled by a processor; (c)a detector, connected to the processor, the detector is positioned such as to detect electrons emitted from the structural element as a result of an interaction with the electron beam. The processor is operable to: (d.1) determine a first traverse section cross sectional feature in response to one or more scans of the structural element with an electron beam that is tilted at

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one or more corresponding tilt angle, such as to illuminate at least the top section and a first transverse section; (d.2) select, in response to a first parameter, whether to (i) determine a second traverse section cross sectional feature in response to the first traverse cross sectional feature, or (ii) to determine the second traverse section cross sectional feature in response to one or more scans of the structural element with an electron beam that is tilted at one or more corresponding tilt angle, such as to illuminate at least the top section and the second transverse section; and (d.3)determine the second traverse section cross sectional feature in response to the selection.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

[0020] Figure 1a is a schematic illustration of a critical dimension scanning electron microscope, in accordance with an embodiment of the invention;

[0021] Figure 1b is a perspective view of an objective lens according to another embodiment of the invention;

[0022] Figure 2a illustrates a perspective as well as a cross sectional view of a line;

[0023] Figure 2b illustrates a cross section of another line that has a top section, a first traverse section that is positively oriented and a negatively oriented second traverse section;

[0024] Figures 3a - 3c are schematic illustration of waveforms that represent a relatively wide positively oriented traverse

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section, a relatively narrow traverse section and a negative oriented traverse section;

[0025] Figures 4-5 are illustrative flow charts of methods for determining a cross sectional feature of a structural element having a sub-micron cross section, in accordance with an embodiment of the invention;

[0026] Figure 6a is a cross sectional view illustrating an exemplary relationship between two electron beam (tilted at a first and a second positive angle) and a structural element;

[0027] Figure 6b is a cross sectional view illustrating an exemplary relationship between two electron beams (tilted at a first and a second negative angle) and a structural element;

[0028] Figure 7 illustrates a cross section and some features that are measured by scanning the cross section with a tilted beam, in accordance to an aspect of the invention;

DETAILED DESCRIPTION OF THE DRAWINGS

[0029] A typical CD-SEM includes an electron gun, for generating an electron beam, deflection and tilt units as well as focusing lens, for enabling scanning of a specimen with an electron beam, that may be in a certain tilt condition, while reducing various aberrations and misalignments. Electrons, such as secondary electrons that are omitted as result of an interaction between the specimen and the electron beam are attracted to a detector that provides detection signals, that are processed by a processing unit. The detection signals may be used to determining various features of the specimen, as well as form images of the inspected specimen.

[0030] The invention may be implemented on CD-SEMs of various architectures that may differ from each other by the amount of their parts as well as the arrangement of said parts. For example the amount of deflection units, as well as the exact

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structure of each unit may vary. The CD-SEM may include in-lens as well as out of lens detectors or a combination of both.

[0031] A block diagram of a critical dimension scanning electron microscope (CD-SEM) 100 is shown schematically in Fig. 1a. CD-SEM 100 includes an electron gun 103 emitting an electron beam 101, which is extracted by the anode 104. The objective lens 112 focuses the electron beam on the specimen surface 105a. The beam is scanned over the specimen using the scanning deflection unit 102. An alignment of the beam to the aperture 106 or a desired optical axis respectively can be achieved by the deflection units 108 to 111. As a deflection unit coils, electrostatic modules in the form of charged plates or a combination of coils and electrostatic deflectors can be used.

[0032] Detector 16 is able to detect secondary electrons that escape from the specimen 105 at a variety of angles with relatively low energy (3 to 50 eV). Measurements of scattered or secondary corpuscles from a specimen can be conducted with detectors in the form of scintillators connected to photomultiplier tubes or the like. Since the way of measuring the signals does not influence the inventive idea in general, this is not to be understood as limiting the invention.

[0033] Detection signals are processed by a processing unit (that me a part of controller 33, but this is not necessarily so) that may have image processing capabilities and is able to process the detection signals in various manners. A typical processing scheme includes generating a waveform that reflects the amplitude of the detection signal versus the scan direction. The waveform is further processed to determine locations of at least one edge, and other cross sectional features of inspected structural elements.

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[0034] The different parts of the system are connected to corresponding supply units (such as high voltage supply unit 21) that are controlled by various control units, most of them are omitted from the figure for simplifying the explanation. The control units may determine the current supplied to a certain part, as well as the voltage.

[0035] CD-SEM 100 includes a double deflection system that includes deflection units 110 and 111. Thus, the beam tilt introduced in the first deflection unit 110, can be corrected for in the second deflection unit 111. Due to this double deflection system, the electron beam can be shifted in one direction without introducing a beam tilt of the electron beam with respect to the optical axis.

[0036] Figure 1b is a perspective view of an objective lens 120 according to another embodiment of the invention. In figure 1b the tilt deflection is performed below (downstream direction) of the objective lens. Objective lens differs from objective lens 102 by having a pole-piece arranged in a quadruple formation, positioned between the objective lens and specimen, for controlling the tilt condition of the electron beam. The polpieces are electrically connected to a ring and a core that bears additional coils (not shown) that are arranged such as to concentrate a magnetic flux at the space between the polepieces, through which the electron beam passes.

[0037] Modern CD-SEMs are able to measure structural elements that have cross sections that have sub-micron dimensions, with an accuracy of several nanometers. The size of these cross section is expected to reduce in the future, as manufacturing and inspection processes continue to improve.

[0038] Various features of the cross section may be of interest. These feature may include, for example: the

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shape of the cross section, the shape of one or more sections of the cross section, the width and/or height and/or angular orientation of the cross section sections, as well as the relationship between cross section sections. The feature can reflect typical values, as well as maximal and/or minimal values. Typically the width of the bottom of a line is of interest, but this is not necessarily so and other features may be of interest.

[0039] Figure 2a illustrates a perspective as well as a cross sectional view of line 210. Line 210 has a cross section 220 that includes a top section 224 and two substantially opposing traverse sections 222 and 226 (that correspond to the top section 214 as well as to two sidewalls 212 and 214 of line 210) that are both positively oriented at substantially opposing angles, such that the bottom of the line is not obscured by the top section 210. Figure 2b illustrates a cross section 230 of another line that has a top section 234, a first traverse section 232 that is positively oriented and a negatively oriented second traverse section 236. Figure 2b also illustrates the convention of positive angles, negative angles and zero angle.

[0040] It is noted that although Figures 2a-2b refer to a line, the method and system are applicable to determine cross sectional features (such as top CD, bottom CD, maximal CD, and the like) of various structural elements, such as contacts, recesses and the like.

[0041] Figures 3a - 3c are schematic illustration of waveforms 250 - 252 that represent a relatively wide positively oriented traverse section, a relatively narrow traverse section and a negative oriented traverse section. As can seen from these figures the waveform portion that is associated with steep

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sidewalls, as well as negative oriented sidewalls is relatively narrow and corresponds to the width f the scanning electron beam.

[0042] Figure 4 illustrates a flow chart of method 400 for determining a cross sectional feature of a structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a first and a second traverse sections.

[0043] Method 400 starts by step 420 of determining a first traverse section cross sectional feature in response to at least one scan of the structural element with an electron beam that is tilted at one or more corresponding tilt angle, such as to illuminate at least the top section and a first transverse section. According to an embodiment of the invention a single tilted scan is enough if the height of the structural element is known or estimated. Else, at least two scans (at different tilt conditions) is required. The height of the structural element may be estimated in response to a height calibration process and/or to information provided by the measured object manufacturer. The calibration process may include multiple measurements of the height of structural elements across the tested object. This process may include mapping the height of structural elements within different regions of the tested object. Said measurement may be implemented by a scanning electron microscope but this is not necessarily so and other tools, such as atomic force microscope, confocal microscopes may be used.

[0044] Step 420 is followed by query step 430 of checking what is the value of a first parameter, which is equivalent to checking whether a predefined first condition was fulfilled, and/or checking whether the value of the first parameter is within a predefined range or ranges. Typically, the first

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parameter determines whether the results of step 420 can be used to estimate a feature of the second section, such as to reduce the amount of scans required for determining a feature of a cross section.

[0045] Briefly, the first condition is fulfilled if the traverse sections may be assumed to be symmetrical. Alternatively or additionally, the first parameter is also responsive to a suspected traverse section measurement, as steep traverse sections, as well as negative oriented traverse sections are associated with certain waveforms. The inventors found that a traverse section is suspected if the width of it substantially equals the width of the electron beam.

[0046] If the first condition is fulfilled, step 430 is followed by step 440 of determining a second traverse section cross sectional feature in response to the first traverse cross sectional feature. Else, step 430 is followed by step 450 of determining a second traverse section cross sectional feature in response to at least one scan of the structural element with an electron beam that is tilted at one or more corresponding tilt angle, such as to illuminate at least the top section and the second transverse section. It is noted that in many cases a single tilted scan is enough as the height of the structural element is known from the results of step 420 (if they are not estimated or previously known in advance).

[0047] The values of the first parameter may be determined in various manners, such as but not limited to the following manners and/or by a combination of these manners: (i) determination by a preliminary calibration process; (ii) determination in response to the symmetry of the waveform acquired during step 420; (iii) determination in response to a correlation between waveform section associated with

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traverse sections, (iv) determination by finding a best matching or substantially matching waveform out of a bank of previously recorded waveforms. It is noted that the waveform may be generated in response to a scan with a tilted electron beam and/or a non-tilted electron beam. The symmetry can be given to the CD-SEM by an end user.

[0048] According to an aspect of the invention the symmetry can be measures by measuring a structural feature (or multiple structural features), rotating the inspected object, locating the previously measured structural object and measuring it from the "opposite" direction.

[0049] The calibration process may include multiple measurements of both sides of multiple structural elements and determination of whether the first condition is fulfilled. The first condition may be also responsive to the required accuracy of the cross sectional feature measurement.

[0050] The value of the first parameter may be alternatively or additionally responsive to a relationship between the width of the electron beam and a width of a waveform portion associated with either the first or second traverse portions, whereas the waveform is acquired during the step of determining a first traverse section cross sectional feature.

[0051] A typical first parameter value can be true or false, but this is not necessarily so, as it may have a range of values that indicate an amount of certainty. When the latter range of values is provided the fulfillment of a first condition may be further responsive to additional parameters such as the required accuracy of the overall measurements, and the like.

[0052] Steps 440 and 450 are followed by step 460 of determining a cross sectional feature of the structural element. As the cross sectional features of the top/intermediate) section are

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known from step 420 and/or step 440, and the first as well as the second features of the first and second traverse sections are also known, various features of the structural element can be calculated. For example, assuming that the first condition was fulfilled, the bottom critical measurement of a line is the width of the top section plus twice the horizontal projection of the first sidewall.

[0053] Figure 5 illustrates a flow chart of method 500 for determining a cross sectional feature of a structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a first and a second traverse sections.

[0054] Method 500 starts at step 510 of scanning the structural element with an electron beam that is tilted at first positive angle in relation to an imaginary line perpendicular to the structural element, to provide a first set of data. An exemplary relationship between an electron beam 600 (tilted at a first positive angle) and a structural element 210 is illustrated in Figure 6a.

[0055] Step 510 is followed by query step 520 of asking if the height of structural element is known (the height of the structural element was previously measured) or is estimated (from measurements of other structural elements, for example during a height calibration process). If the answer is negative jumping to step 530, else jumping to step 540.

[0056] Step 530 includes scanning the structural element with an electron beam that is tilted at second positive angle in relation to an imaginary line perpendicular to the structural element, to provide a second set of data. An exemplary relationship between an electron beam 610 (tilted at a second positive angle) and a structural element 210 is illustrated in Figure 6a. Step 530 is followed by step 540.

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[0057] Step 540 involves determining a first traverse section cross sectional feature in response of at least the first set of data. Conveniently, if step 530 was skipped the feature is determined in response to the first set of data while if step 530 was performed, the determination of the feature is responsive to both data sets. It is noted that both data sets may be graphically illustrated as a waveform.

[0058] Step 540 is followed by a query step 550 of checking what is the value of a first parameter. Those of skill in the art will appreciate that this is analogues to asking whether the value of the first parameter is within a certain range (or ranges). The value of the first parameter is used to determine whether a second traverse section cross sectional feature can be figured out from the first traverse section cross sectional feature. As illustrated in further details in the previous pages, the determination is responsive to an estimated symmetry between the first and second traverse sections and/or to the width of these traverse sections.

[0059] If the second traverse section cross sectional feature must be measured step 550 is followed by step 560, else step 550 is followed by step 601.

[0060] Step 601 includes determining a second traverse section cross sectional feature in response to the first traverse cross sectional feature. Step 601 as well as step 580 are usually followed by an additional step of determining a cross sectional feature of the structural element.

[0061] Step 560 includes scanning the structural element with an electron beam that is tilted at first negative angle in relation to an imaginary line perpendicular to the structural element, to provide a third set of data. An exemplary relationship between an electron beam 620 (tilted at first

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negative angle) and a structural element is illustrated in Figure 6b.

[0062] Step 560 is followed by query step 570 of asking if the height of structural element is known (the height of the structural element was previously measured) or is estimated (from measurements of other structural elements, for example during a height calibration process). If the answer is negative jumping to step 580, else jumping to step 590.

[0063] Step 580 includes scanning the structural element with an electron beam that is tilted at second negative angle in relation to an imaginary line perpendicular to the structural element, to provide a fourth set of data. An exemplary relationship between an electron beam 630 (tilted at second negative angle) and a structural element is illustrated in Figure 6b. Step 580 is followed by step 590.

[0064] Step 590 involves determining a second traverse section cross sectional feature in response of at least the third set of data. Conveniently, if step 580 was skipped the feature is determined in response to the third set of data while if step 580 was performed, the determination of the feature is responsive to both third and fourth data sets. It is noted that both data sets may be graphically illustrated as a waveform.

[0065] Is noted that the intermediate section, which may be a top section in the case of an elevated structural element, may be determined from each of the scanning steps. It is further noted that given the first and second traverse section cross sectional features the cross section of the structural element as well as any feature (such as but not limited to top CD, bottom CD, maximal CD) of said cross section can be determined. A typical cross sectional feature is the horizontal projection of a traverse section. In cases where

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the tilt angle is relatively small it is assumed that the tilt angle is approximately equal to the Tangents of this angle.

[0066] It is noted that some of the measurements may be repeated, and that additional tilted scans of the structural element (with the same and/or differing tilt angles) may be performed for various reasons, such as averaging out statistical noise, and the like. Accordingly methods 400 and 500 may include multiple measurements of one or more cross sectional features, even if the height of the structural elements in known or estimated and even if a certain cross sectional feature was measured.

[0067] Figure 7 illustrates a cross section and some features that are measured by scanning the cross section with a tilted beam, in accordance to an aspect of the invention.

[0068] Referring to Figure 7 the following variables have the following meaning:

[0069] Z= height of line; X_T - width of top of line ("top Critical dimension"); X_{ER} - horizontal projection of right side wall; X_{EL} - horizontal projection of right side wall; X_B - horizontal projection of the bottom of the line ("bottom Critical Dimension"); α - positive tilt angle; E_E - measured dimension of a sidewall at tilt angle α.

[0070] If two measurements are made, from the same side, at two different positive angles (α_{L1} and α_{L2}) and at two different negative angles (α_{R1} and α_{R2}), then: E_{ER1} - measured dimension of right sidewall at tilted angle α_{R1}; E_{ER2} - measured dimension of right sidewall at tilted angle α_{R2}; E_{EL1} - measured dimension of right sidewall at tilted angle α_{L1}; E_{EL2} - measured dimension of right sidewall at tilted angle α_{L2}. It is also assumed that the tilt angles (α) are small such that the α = Tangent(α).

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[0071] Given said variables the bottom critical dimension can be calculated by using at least one of the following sets of equations:

[0072] First set (If first condition fulfilled): $X_B=\underline{X}_T+2*X_E$; $\underline{X}_T=(X_T+E_{R1}+E_{R2})/3$; $X_E=E_{E1}-\alpha_1*(E_{E1}-E_{E2})/(\alpha_1-\alpha_2)$.

[0073] Second set (If first condition is not fulfilled): $X_B=\underline{X}_T+X_{EL}+X_{ER}$; $\underline{X}_T=(X_T+E_{R1}+E_{R2}+E_{L1}+E_{L2})/5$; $X_{EL}=E_{EL1}-\alpha_{L1}*\underline{Z}$; $X_{ER}=E_{ER1}-\alpha_{R1}*\underline{Z}$; $\underline{Z}=\{(E_{E1}-E_{E2})/2(\alpha_{L1}-\alpha_{L2})+(E_{R1}-E_{R2})/2(\alpha_{R1}-\alpha_{R2})\}$.

[0074] The present invention can be practiced by employing conventional tools, methodology and components. Accordingly, the details of such tools, component and methodology are not set forth herein in detail. In the previous descriptions, numerous specific details are set forth, such as shapes of cross sections of typical lines, amount of deflection units, etc., in order to provide a thorough understanding of the present invention. However, it should be recognized that the present invention might be practiced without resorting to the details specifically set forth.

[0075] Only exemplary embodiments of the present invention and but a few examples of its versatility are shown and described in the present disclosure. It is to be understood that the present invention is capable of use in various other combinations and environments and is capable of changes or modifications within the scope of the inventive concept as expressed herein.

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We claim

1. A method for determining a cross sectional feature of a structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a first and a second traverse sections, the method comprising the steps of:

determining a first traverse section cross sectional feature in response to at least one scan of the structural element with an electron beam that is tilted at at least one corresponding tilt angle, such as to illuminate at least the top section and a first transverse section;

selecting, in response to a first parameter, whether to (i) determine a second traverse section cross sectional feature in response to the first traverse cross sectional feature, or (ii) to determine the second traverse section cross sectional feature in response to at least one scan of the structural element with an electron beam that is tilted at at least one corresponding tilt angle, such as to illuminate at least the top section and the second transverse section; and

determining the second traverse section cross sectional feature in response to the selection.

2. The method of claim 1 wherein the first parameter value is responsive to an estimated symmetry of the first and second traverse sections.

3. The method of claim 1 wherein the first parameter value is determined during a calibration process.

4. The method of claim 3 wherein a tested object comprises the sub micron structural element as well as other sub micron structural elements; and whereas the

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calibration process involves measuring first and second cross sectional of at least two out of the other sub micron structural elements.

5. The method of claim 1 wherein the first parameter value is responsive to a symmetry of a waveform acquired as a result of the scan of the structural element with an electron beam that is tilted such as to illuminate at least the top section and a first transverse section.

6. The method of claim 1 wherein the first parameter value is responsive to a symmetry of a waveform acquired as a result of the scan of the structural element with an electron beam that is substantially normal to a test object that comprises the sub micron structural element.

7. The method of claim 1 wherein the first parameter value is responsive to a correlation between a first waveform portion that is associated with the first traverse section and between a second waveform portion that is associated with the second traverse section.

8. The method of claim 1 wherein the first parameter value is determined by: acquiring a waveform as a result of the scan of the structural element with an electron beam that is tilted such as to illuminate at least the top section and a first transverse section; locating, out of a plurality of previously recorded waveforms associated with previously calculated first parameter values, a previously recorded best matching waveform; determining the first parameter in response to the previously calculated correlation factor of the previously recorded best matching waveform.

9. The method of claim 1 wherein the first condition value is responsive to a relationship between the width of the electron beam and a width of a waveform portion

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associated with either the first or second traverse portions, whereas the waveform is acquired during the step of determining a first traverse section cross sectional feature.

10. The method of claim 1 wherein the step of determining a first traverse section cross sectional feature comprises multiple scans at multiple corresponding tilt angles if the height of the structural element is not known or estimated.

11. The method of claim 10 wherein the height of the structural element is estimated in response to a height calibration process.

12. The method of claim 11 wherein the height calibration proves comprises measuring the height of multiple structural element of a test object that are ideally of the same height.

13. The method of claim 1 wherein the structural element is line that has a top section and two substantially opposing sidewalls.

14. The method of claim 1 wherein the structural element is a contact.

15. The method of claim 1 wherein the structural element is a recess.

16. A method for determining a cross sectional feature of a structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a first and a second traverse sections, the method comprising the steps of:

scanning the structural element with an electron beam that is tilted at first positive angle in relation to an imaginary line perpendicular to the structural element, to provide a first set of data;

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scanning the structural element with an electron beam that is tilted at second positive angle in relation to an imaginary line perpendicular to the structural element, to provide a second set of data, if the height of the structural element in not known or not estimated;

determining a first traverse section cross sectional feature in response of at least the first set of data;

determining a second traverse section cross sectional feature in response to the first traverse cross sectional feature, if a first parameter has a certain value;

whereas if the first parameter has another value performing the steps of:

scanning the structural element with an electron beam that is tilted at first negative angle in relation to an imaginary line perpendicular to the structural element, to provide a third set of data;

scanning the structural element with an electron beam that is tilted at second negative angle in relation to an imaginary line perpendicular to the structural element, to provide a fourth set of data, if the height of the structural element in not known or not estimated;

determining a second traverse section cross sectional feature in response of at least the third set of data.

17. The method of claim 16 wherein the first parameter value is responsive to an estimated symmetry of the first and second traverse sections.

18. The method of claim 16 wherein the first parameter value is determined during a calibration process.

19. The method of claim 18 wherein a tested object comprises the sub micron structural element as well as

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other sub micron structural elements; and whereas the calibration process involves measuring first and second cross sectional of at least two out of the other sub micron structural elements.

20. The method of claim 16 wherein the first parameter value is responsive to a symmetry of a waveform acquired as a result of the scan of the structural element with an electron beam that is tilted such as to illuminate at least the top section and a first transverse section.

21. The method of claim 16 wherein the first parameter value is responsive to a symmetry of a waveform acquired as a result of the scan of the structural element with an electron beam that is substantially normal to a test object that comprises the sub micron structural element.

22. The method of claim 16 wherein the first parameter value is responsive to a correlation between a first waveform portion that is associated with the first traverse section and between a second waveform portion that is associated with the second traverse section.

23. The method of claim 16 wherein the first parameter value is determined by: acquiring a waveform as a result of the scan of the structural element with an electron beam that is tilted such as to illuminate at least the top section and a first transverse section; locating, out of a plurality of previously recorded waveforms associated with previously calculated first parameter values, a previously recorded best matching waveform; determining the first parameter in response to the previously calculated correlation factor of the previously recorded best matching waveform.

24. The method of claim 16 wherein the first condition value is responsive to a relationship between the width of

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the electron beam and a width of a waveform portion associated with either the first or second traverse portions, whereas the waveform is acquired during the step of determining a first traverse section cross sectional feature.

25. The method of claim 16 wherein the step of determining a first traverse section cross sectional feature comprises multiple scans at multiple corresponding tilt angles it the height of the structural element is not known or estimated.

26. The method of claim 25 wherein the height of the structural element is estimated in response to a height calibration process.

27. The method of claim 26 wherein the height calibration proves comprises measuring the height of multiple structural element of a test object that are ideally of the same height.

28. The method of claim 16 wherein the structural element is line that has a top section and two substantially opposing sidewalls.

29. The method of claim 16 wherein the structural element is a contact.

30. The method of claim 16 wherein the structural element is a recess.

31. An system for determining a cross sectional feature of a structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a first and a second traverse sections, the system comprises:

first means for generating an electron beam;

second means for scanning the electron beam across a structural element of a measured object and for determining

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a tilt angle of the electron beam; whereas the second means is coupled to a processor and controlled by the processor;

a detector, coupled to the processor, the detector is positioned such as to detect electrons emitted from the structural element as a result of an interaction with the electron beam;

whereas the processor is operable to:

determine a first traverse section cross sectional feature in response to at least one scan of the structural element with an electron beam that is tilted at at least one corresponding tilt angle, such as to illuminate at least the top section and a first transverse section;

select, in response to a first parameter, whether to (i) determine a second traverse section cross sectional feature in response to the first traverse cross sectional feature, or (ii) to determine the second traverse section cross sectional feature in response to at least one scan of the structural element with an electron beam that is tilted at at least one corresponding tilt angle, such as to illuminate at least the top section and the second transverse section; and

determine the second traverse section cross sectional feature in response to the selection.

32. The system of claim 31 wherein the first parameter value is responsive to an estimated symmetry of the first and second traverse sections.

33. The system of claim 31 wherein the first parameter value is determined during a calibration process.

34. The system of claim 33 wherein a tested object comprises the sub micron structural element as well as other sub micron structural elements; and whereas the calibration process involves measuring first and second

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cross sectional of at least two out of the other sub micron structural elements.

35. The system of claim 31 wherein the first parameter value is responsive to a symmetry of a waveform acquired as a result of the scan of the structural element with an electron beam that is tilted such as to illuminate at least the top section and a first transverse section.

36. The system of claim 31 wherein the first parameter value is responsive to a symmetry of a waveform acquired as a result of the scan of the structural element with an electron beam that is substantially normal to a test object that comprises the sub micron structural element.

37. The system of claim 31 wherein the system is operable to determine the value of the first parameter in responsive to a correlation between a first waveform portion that is associated with the first traverse section and between a second waveform portion that is associated with the second traverse section.

38. The system of claim 31 wherein system is operable to determine the first parameter value by an acquisition of a waveform as a result of the scan of the structural element with an electron beam that is tilted such as to illuminate at least the top section and a first transverse section; a location, out of a plurality of previously recorded waveforms associated with previously calculated first parameter values, a previously recorded best matching waveform; and determination of the first parameter in response to the previously calculated correlation factor of the previously recorded best matching waveform.

39. The system of claim 31 wherein the first condition value is responsive to a relationship between the width of the electron beam and a width of a waveform portion

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associated with either the first or second traverse portions, whereas the waveform is acquired during the step of determining a first traverse section cross sectional feature.

40. The system of claim 31 wherein the system is operable to determine a first traverse section cross sectional feature by multiple scans at multiple corresponding tilt angles it the height of the structural element is not known or estimated.

41. The system of claim 40 wherein the system is operable to estimate a height of the structural element in response to a height calibration process.

42. The system of claim 41 wherein the height calibration proves comprises measuring the height of multiple structural element of a test object that are ideally of the same height.

43. The system of claim 31 wherein the structural element is line that has a top section and two substantially opposing sidewalls.

44. The system of claim 31 wherein the structural element is a contact.

45. The system of claim 31 wherein the structural element is a recess.

46. An system for determining a cross sectional feature of a structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a first and a second traverse sections, the system comprises:

first means for generating an electron beam;

second means for scanning the electron beam across a structural element of a measured object and for determining

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a tilt angle of the electron beam; whereas the second means is coupled to a processor and controlled by the processor;

a detector, coupled to the processor, the detector is positioned such as to detect electrons emitted from the structural element as a result of an interaction with the electron beam;

whereas the processor is operable to:

control the second means such that the structural element is scanned with an electron beam that is tilted at first positive angle in relation to an imaginary line perpendicular to the structural element, to provide a first set of data;

control the second means such that the structural element is scanned with an electron beam that is tilted at second positive angle in relation to an imaginary line perpendicular to the structural element, to provide a second set of data, if the height of the structural element in not known or not estimated;

determine a first traverse section cross sectional feature in response of at least the first set of data;

determine a second traverse section cross sectional feature in response to the first traverse cross sectional feature, if a first parameter has a certain value;

whereas if the first parameter has another value,

control the second means such that the structural element is scanned with an electron beam that is tilted at first negative angle in relation to an imaginary line perpendicular to the structural element, to provide a third set of data;

control the second means such that the structural element is scanned with an electron beam that is tilted at second negative angle in relation to an

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imaginary line perpendicular to the structural element, to provide a fourth set of data, if the height of the structural element in not known or not estimated;

determine a second traverse section cross sectional feature in response set of data.

47. The system of claim 46 wherein the first parameter value is responsive to an estimated symmetry of the first and second traverse sections.

48. The system of claim 46 wherein the first parameter value is determined during a calibration process.

49. The system of claim 48 wherein a tested object comprises the sub micron structural element as well as other sub micron structural elements; and whereas the calibration process involves measuring first and second cross sectional of at least two out of the other sub micron structural elements.

50. The system of claim 46 wherein the first parameter value is responsive to a symmetry of a waveform acquired as a result of the scan of the structural element with an electron beam that is tilted such as to illuminate at least the top section and a first transverse section.

51. The system of claim 46 wherein the first parameter value is responsive to a symmetry of a waveform acquired as a result of the scan of the structural element with an electron beam that is substantially normal to a test object that comprises the sub micron structural element.

52. The system of claim 46 wherein the system is operable to determine the value of the first parameter in responsive to a correlation between a first waveform portion that is associated with the first traverse section and between a

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second waveform portion that is associated with the second traverse section.

53. The system of claim 46 wherein system is operable to determine the first parameter value by an acquisition of a waveform as a result of the scan of the structural element with an electron beam that is tilted such as to illuminate at least the top section and a first transverse section; a location, out of a plurality of previously recorded waveforms associated with previously calculated first parameter values, a previously recorded best matching waveform; and determination of the first parameter in response to the previously calculated correlation factor of the previously recorded best matching waveform.

54. The system of claim 46 wherein the first condition value is responsive to a relationship between the width of the electron beam and a width of a waveform portion associated with either the first or second traverse portions, whereas the waveform is acquired during the step of determining a first traverse section cross sectional feature.

55. The system of claim 46 wherein the system is operable to determine a first traverse section cross sectional feature by multiple scans at multiple corresponding tilt angles it the height of the structural element is not known or estimated.

56. The system of claim 55 wherein the system is operable to estimate a height of the structural element in response to a height calibration process.

57. The system of claim 56 wherein the height calibration proves comprises measuring the height of multiple structural element of a test object that are ideally of the same height.

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58. The system of claim 46 wherein the structural element is line that has a top section and two substantially opposing sidewalls.

59. The system of claim 46 wherein the structural element is a contact.

60. The system of claim 46 wherein the structural element is a recess.

61. The method of claim 1 wherein one tilt angle is substantially zero.

62. The method of claim 16 wherein one tilt out of the first positive angle and first negative angle is substantially zero.

63. The system of claim 31 wherein one tilt angle is substantially zero.

64. The system of claim 46 wherein one tilt out of the first positive angle and first negative angle is substantially zero.

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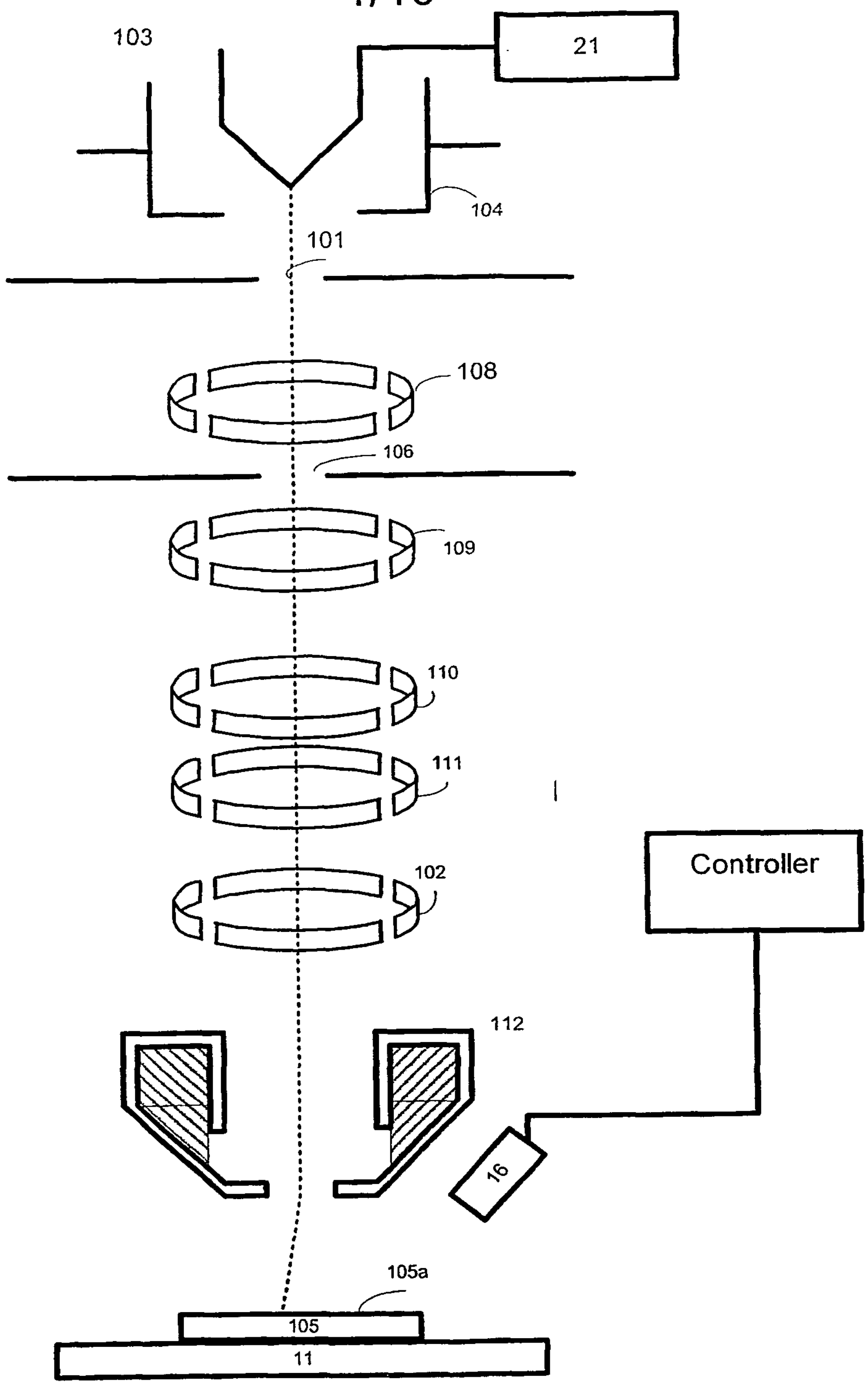

Figure 1a

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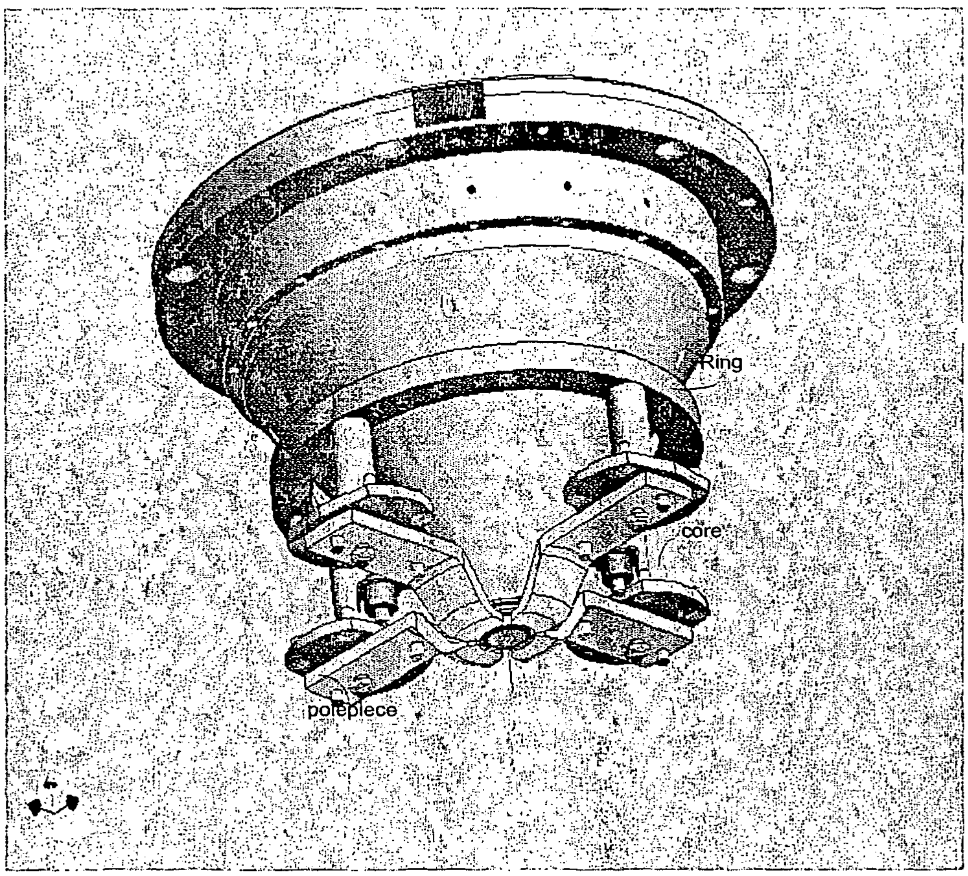


FIGURE 1b

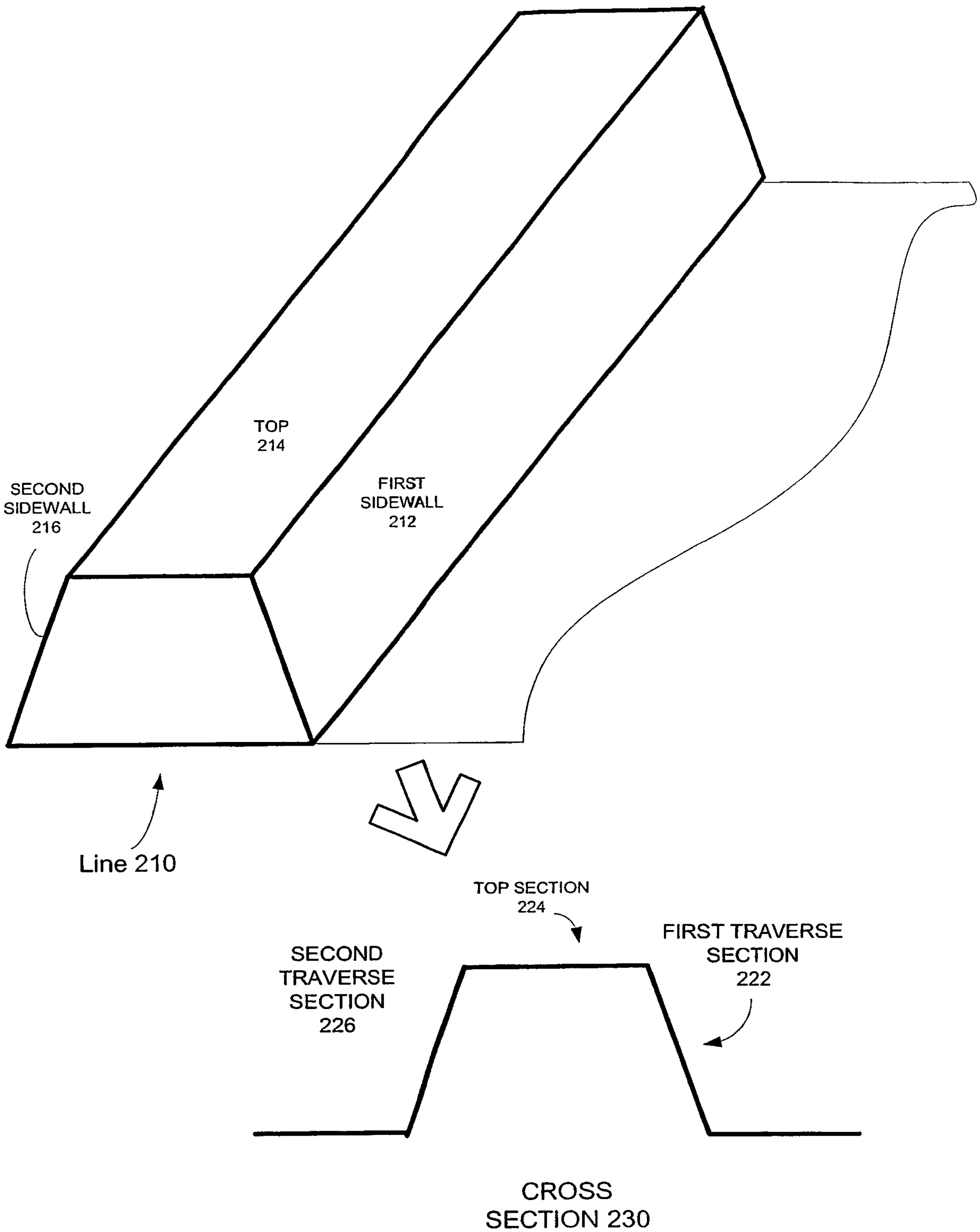
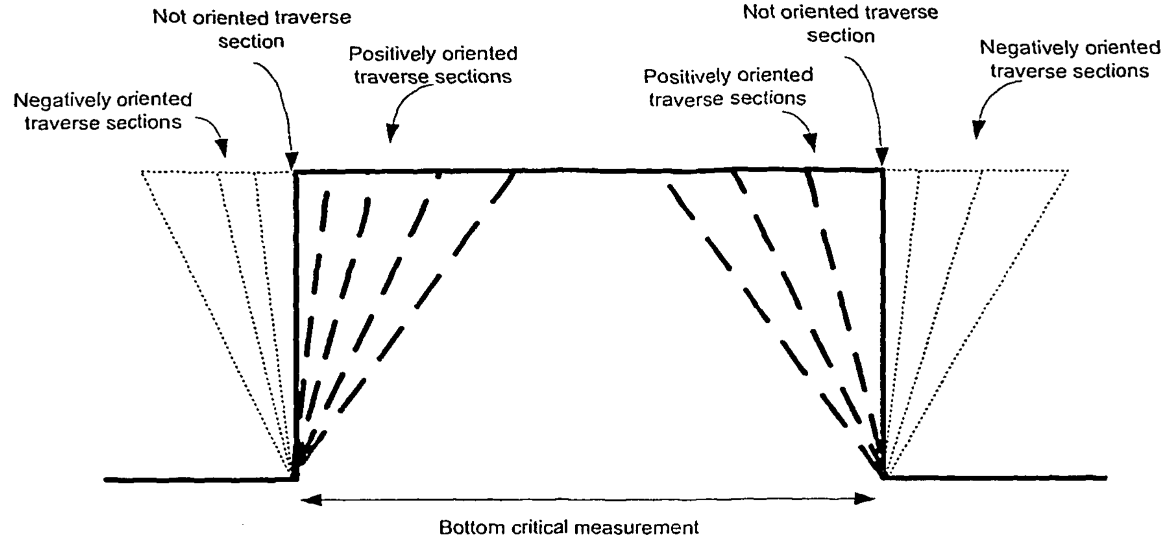
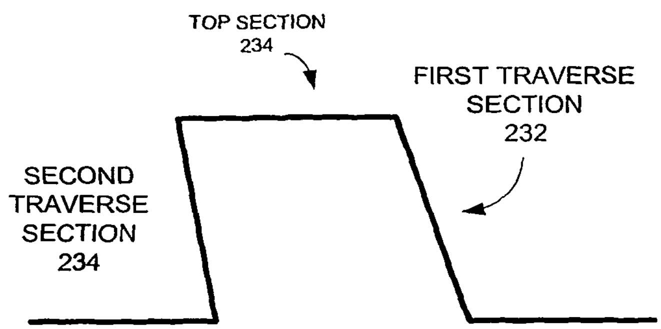

TOP
214
SECOND
SIDEWALL
216
FIRST
SIDEWALL
212
Line 210
TOP SECTION
224
SECOND
TRAVERSE
SECTION
226
FIRST TRAVERSE
SECTION
222
CROSS
SECTION 230

FIGURE 2a





CROSS SECTION 230

FIGURE 2b

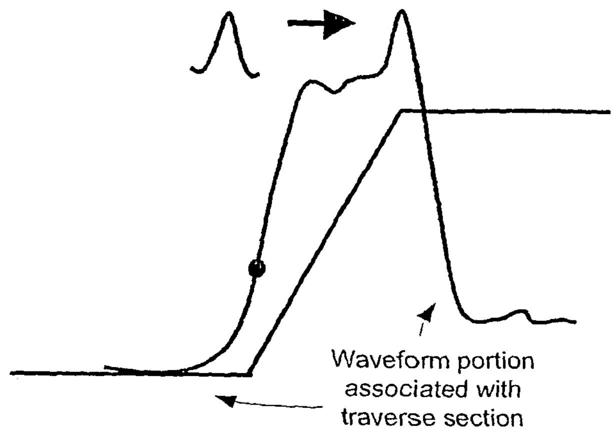


FIGURE 3a

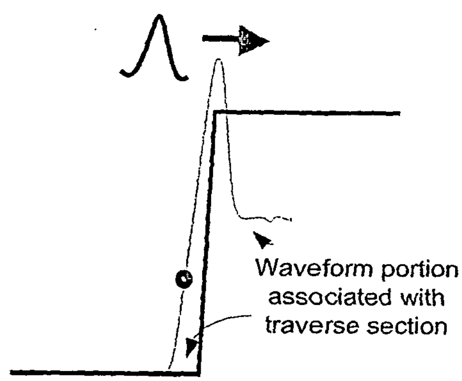


FIGURE 3b

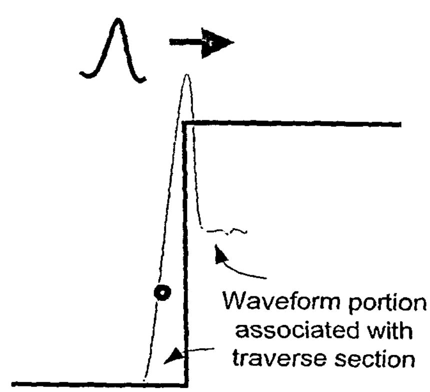


FIGURE 3c

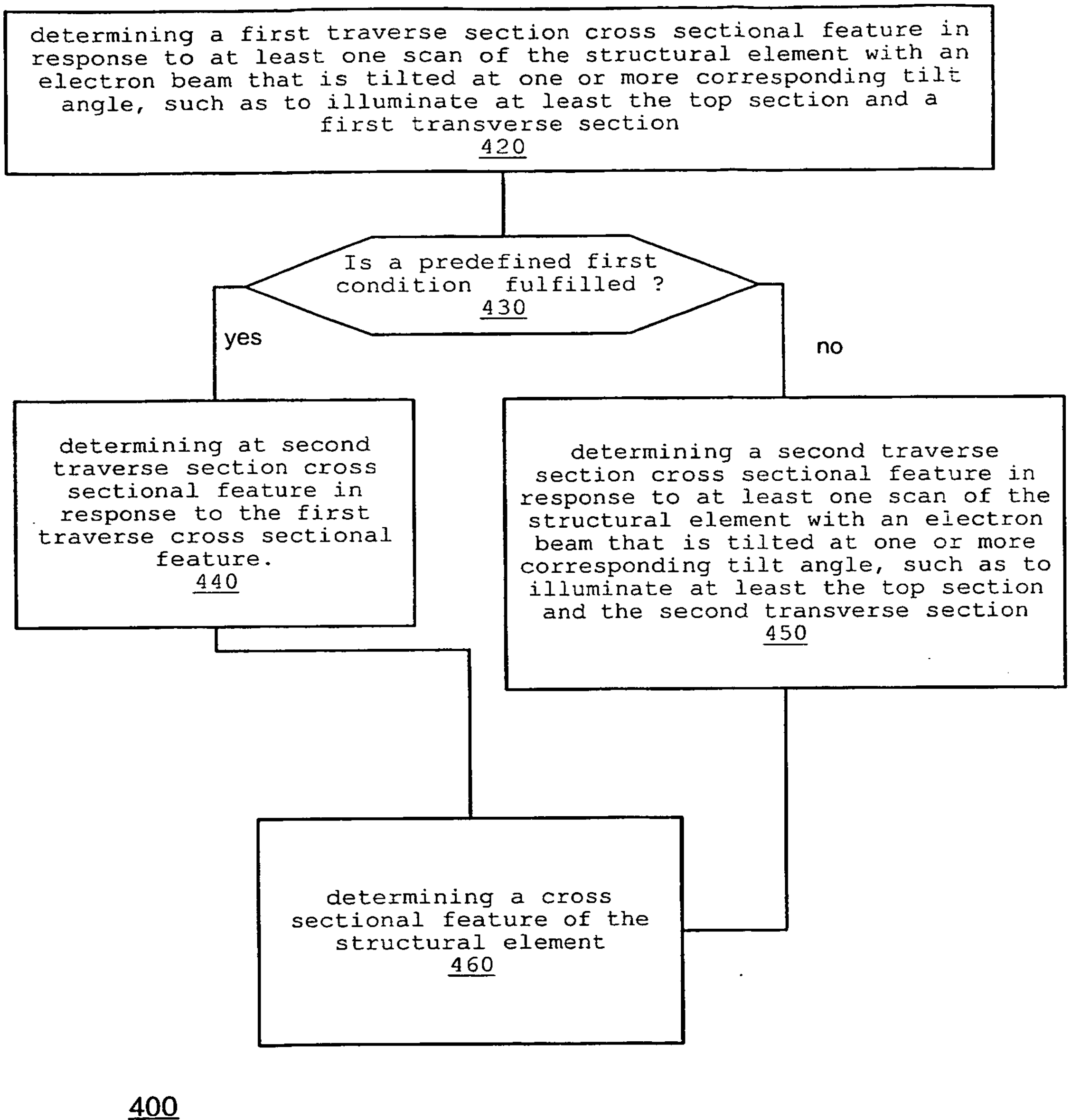

determining a first traverse section cross sectional feature in response to at least one scan of the structural element with an electron beam that is tilted at one or more corresponding tilt angle, such as to illuminate at least the top section and a first transverse section
420
Is a predefined first condition fulfilled ?
430
yes
no
determining at second traverse section cross sectional feature in response to the first traverse cross sectional feature.
440
determining a second traverse section cross sectional feature in response to at least one scan of the structural element with an electron beam that is tilted at one or more corresponding tilt angle, such as to illuminate at least the top section and the second transverse section
450
determining a cross sectional feature of the structural element
460
400

FIGURE 4

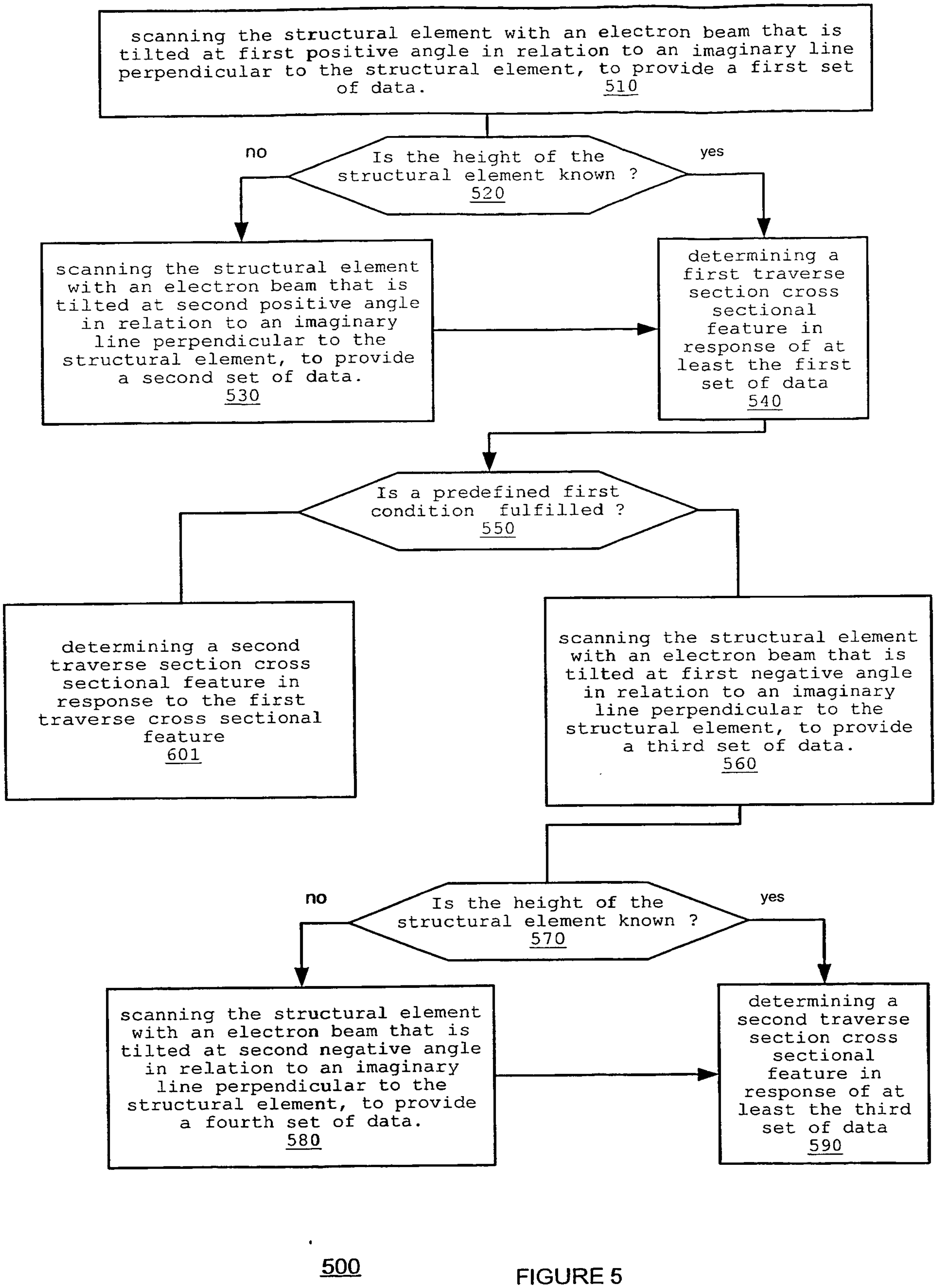

scanning the structural element with an electron beam that is tilted at first positive angle in relation to an imaginary line perpendicular to the structural element, to provide a first set of data. 510
no
Is the height of the structural element known ? 520
yes
scanning the structural element with an electron beam that is tilted at second positive angle in relation to an imaginary line perpendicular to the structural element, to provide a second set of data. 530
determining a first traverse section cross sectional feature in response of at least the first set of data 540
Is a predefined first condition fulfilled ? 550
determining a second traverse section cross sectional feature in response to the first traverse cross sectional feature 601
scanning the structural element with an electron beam that is tilted at first negative angle in relation to an imaginary line perpendicular to the structural element, to provide a third set of data. 560
no
Is the height of the structural element known ? 570
yes
scanning the structural element with an electron beam that is tilted at second negative angle in relation to an imaginary line perpendicular to the structural element, to provide a fourth set of data. 580
determining a second traverse section cross sectional feature in response of at least the third set of data 590
500

FIGURE 5

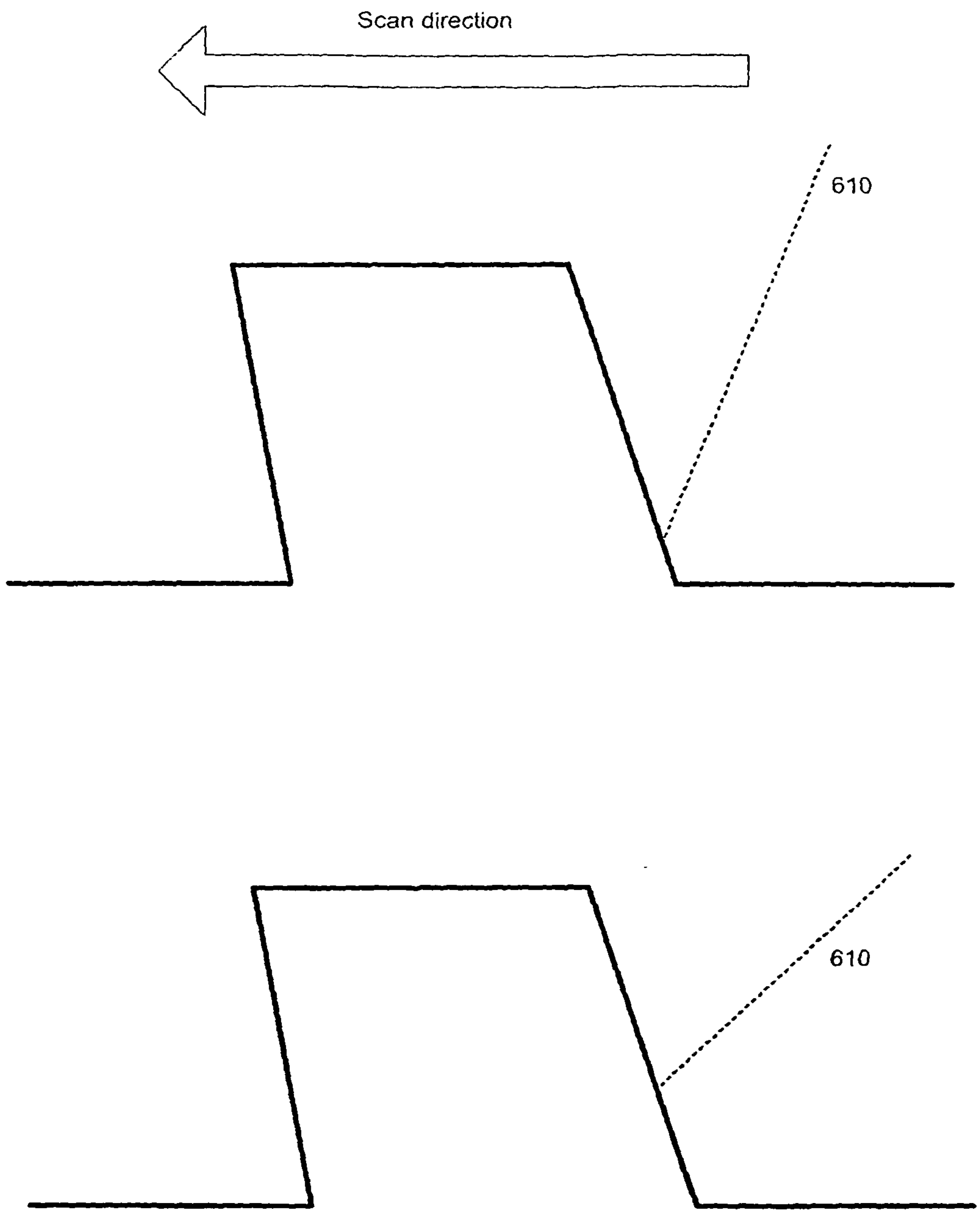


FIGURE 6a

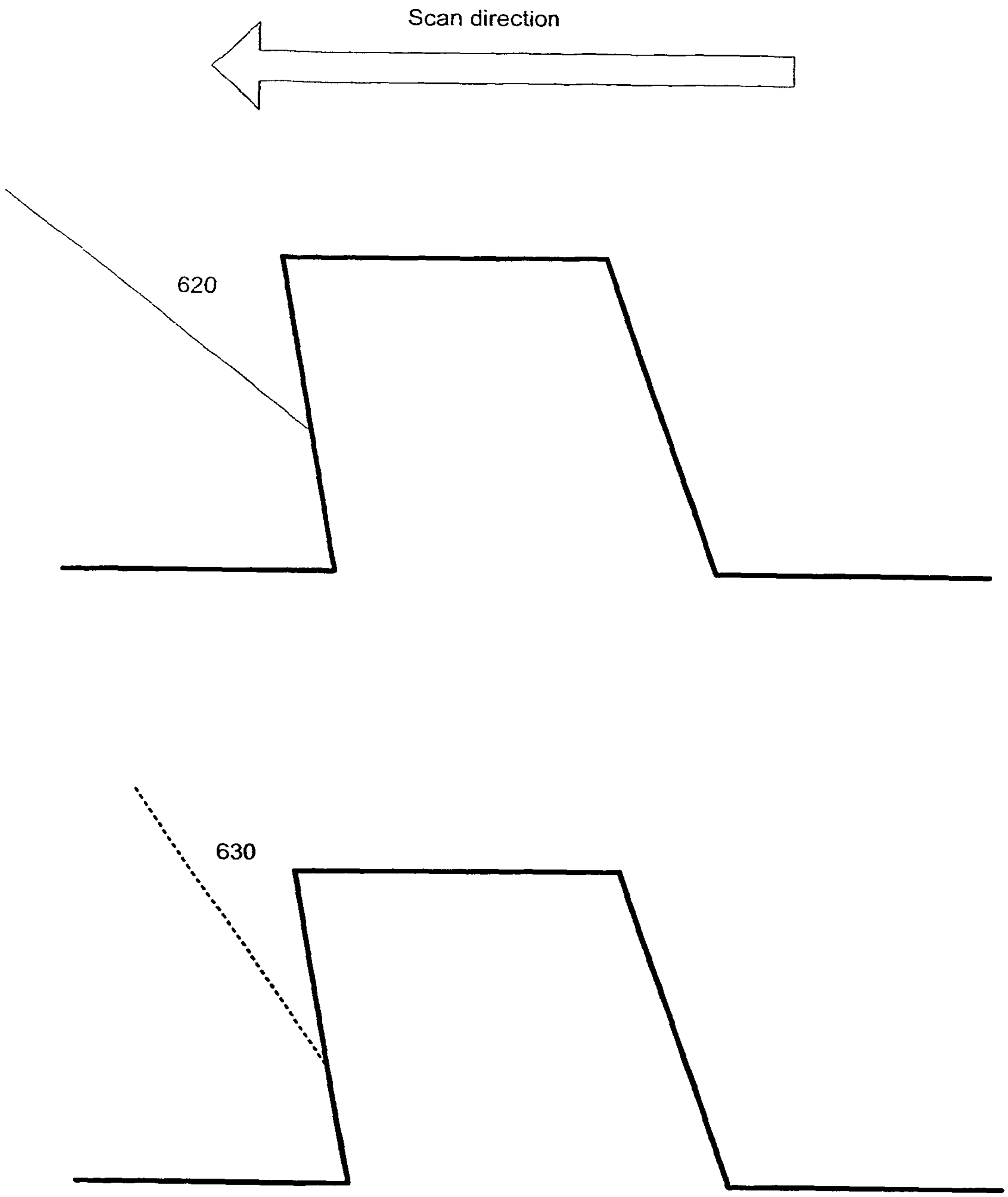


FIGURE 6b

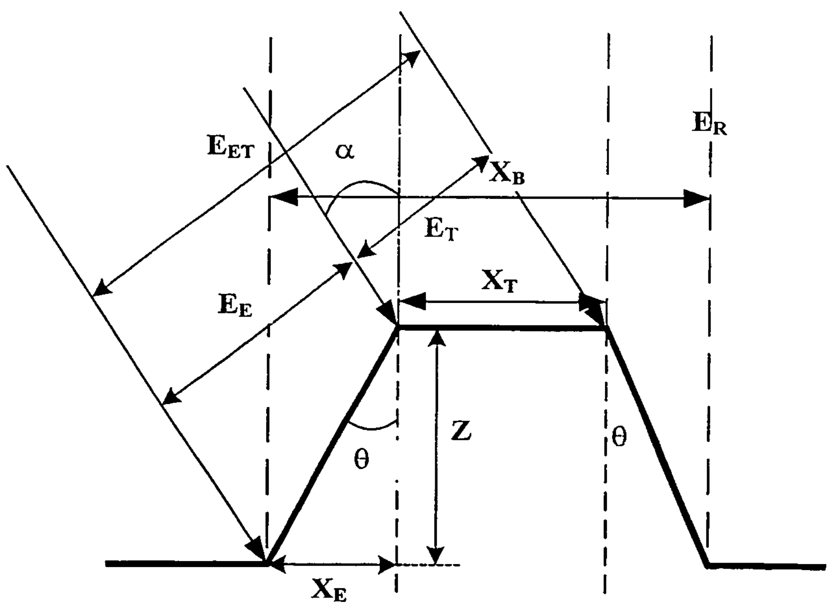


Figure 7

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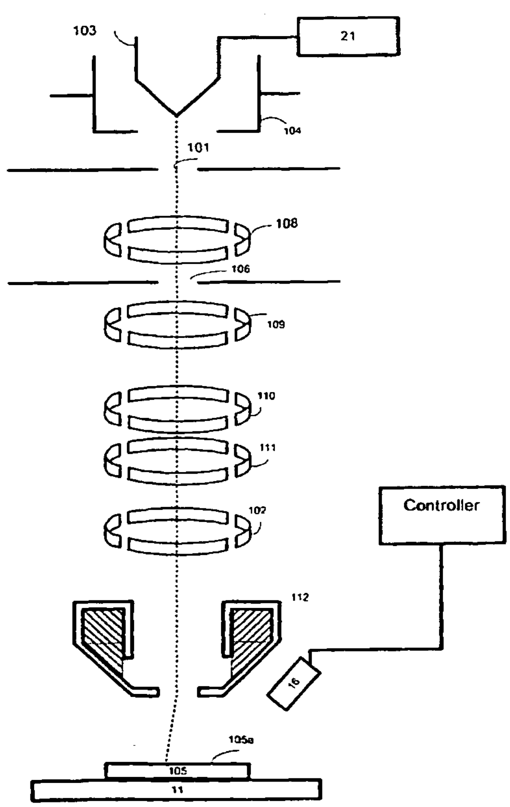
[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR MEASURING CRITICAL DIMENSIONS WITH A PARTICLE BEAM



(57) Abstract: A method and system for determining a cross sectional feature of a structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a first and a second traverse sections. The method includes: (a) determining a first traverse section cross sectional feature in response to one or more scans of the structural element with an electron beam that is tilted at one or more corresponding tilt angle, such as to illuminate at least the top section and a first transverse section; (b) selecting, in response to a first parameter, whether to (i) determine a second traverse section cross sectional feature in response to the first traverse cross sectional feature, or (ii) to determine the second traverse section cross sectional feature in response to one or more scans of the structural element with an electron beam that is tilted at one or more corresponding tilt angle, such as to illuminate at least the top section and the second transverse section; and (c) determining the second traverse section cross sectional feature in response to the selection.

WO 2004/008255 A3

(84) **Designated States** *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

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(88) **Date of publication of the international search report:** 10 June 2004

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

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International Application No
PCT/US 03/21690

A. CLASSIFICATION OF SUBJECT MATTER
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According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01N G01B G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 01/045136 A (ADAMEC PAVEL ; GOLDENSHTEIN ALEX (IL); PEARL ASHER (IL); PETROV IGOR () 21 June 2001 (2001-06-21) page 12, line 24 - page 14, line 11; figures	1-64
X	EP 0 441 373 A (TOKYO SHIBAURA ELECTRIC CO) 14 August 1991 (1991-08-14) page 5, line 5 - page 7, line 5; figures	1-64
X	PATENT ABSTRACTS OF JAPAN vol. 0103, no. 22 (P-511), 31 October 1986 (1986-10-31) & JP 61 128114 A (TOSHIBA CORP), 16 June 1986 (1986-06-16) abstract	1,16,31, 46

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
11 February 2004	24/02/2004

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European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Savage, J

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 03/21690

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	FINNES S J AND SMITH G J: "Nondestructive Slope/Thickness Measurement for Semiconductor Topology" IBM TECHNICAL DISCLOSURE BULLETIN, IBM CORP. NEW YORK, US, vol. 26, no. 1, 1 June 1983 (1983-06-01), pages 189-190, XP002153556 ISSN: 0018-8689 the whole document -----	1,16,31, 46
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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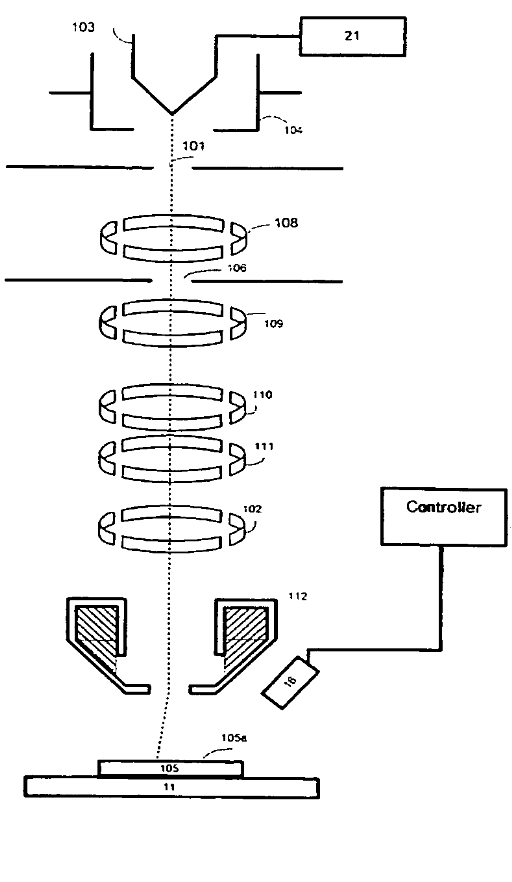
(54) Title: METHOD AND APPARATUS FOR MEASURING CRITICAL DIMENSIONS WITH A PARTICLE BEAM



(57) **Abstract:** A method and system for determining a cross sectional feature of a structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a first and a second traverse sections. The method includes: (a) determining a first traverse section cross sectional feature in response to one or more scans of the structural element with an electron beam that is tilted at one or more corresponding tilt angle, such as to illuminate at least the top section and a first transverse section; (b) selecting, in response to a first parameter, whether to (i) determine a second traverse section cross sectional feature in response to the first traverse cross sectional feature, or (ii) to determine the second traverse section cross sectional feature in response to one or more scans of the structural element with an electron beam that is tilted at one or more corresponding tilt angle, such as to illuminate at least the top section and the second transverse section; and (c) determining the second traverse section cross sectional feature in response to the selection.

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